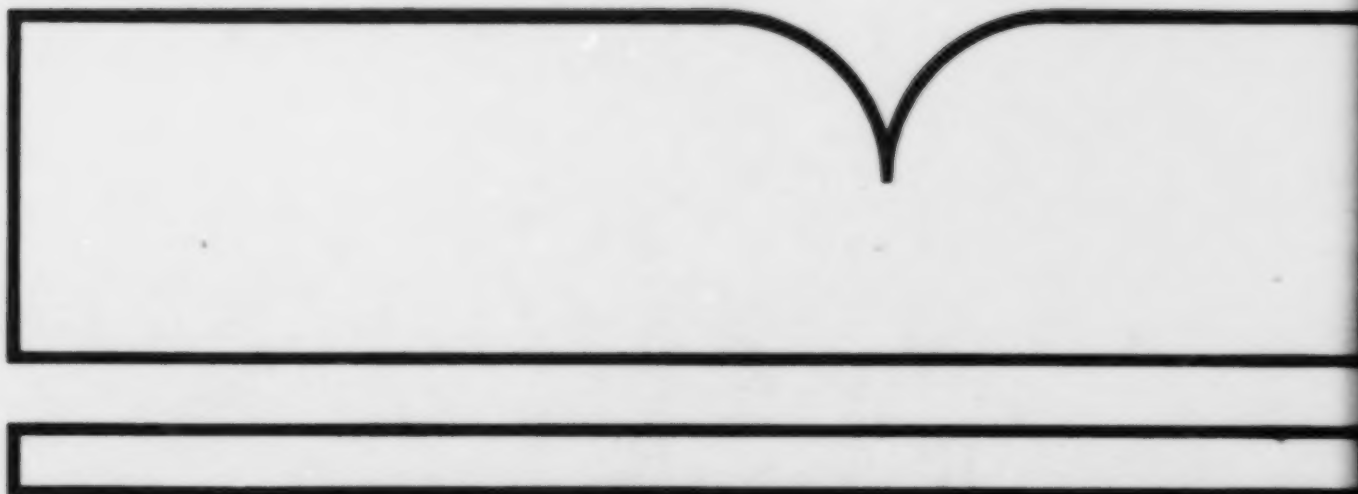


Emissions and Fuel Economy of a
Comprex Pressure Wave Supercharged Diesel

(U.S.) Environmental Protection Agency
Ann Arbor, MI

Oct 80



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Test and Evaluation Branch
Emission Control Technology Division
Office of Mobile Source Air Pollution Control
Office of Air, Noise, and Radiation
Environmental Protection Agency

Background

The Environmental Protection Agency (EPA) receives information about many systems which appear to offer potential for emissions reduction or fuel economy improvement compared to conventional engines and vehicles. The Emission Control Technology Division of the EPA is interested in evaluating all such systems, because of the obvious benefits to the Nation from the identification of such systems. EPA invites developers of such systems to provide complete technical data on the system's principle of operation, together with available test data on the system. In those cases for which review by EPA technical staff suggests that the data available show promise, confirmatory tests are conducted at the EPA Motor Vehicle Emission Laboratory at Ann Arbor, Michigan. The results of all such test projects are set forth in a series of Test and Evaluation Reports, of which this report is one.

To reduce the nation's dependence upon foreign oil, the Congress of the United States imposed Fuel Economy Regulations for new motor vehicles. These regulations have become an impetus for increased diesel engine application for light duty passenger car use. In order to increase public interest in vehicles equipped with diesel engines, methods of improving diesel-fueled engine performance, as compared to current gasoline-fueled counterparts, are being investigated. One method to increase performance is to supercharge or turbocharge the engine. This report details an EPA assessment of a supercharging technique previously evaluated [1]*, however, since that evaluation, specific areas of operation have been refined.

The conclusions from the EPA evaluation testing can be considered to be quantitatively valid only for the specific test car used; however, it is reasonable to extrapolate the results from the EPA testing to other types of vehicles in a directional manner, i.e. to suggest that similar results are likely to be achieved on other types of vehicles.

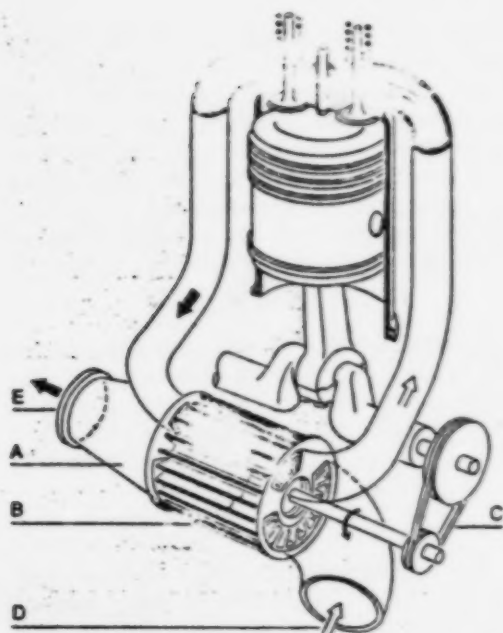
System Description

The vehicle used for this assessment was an Opel Rekord equipped with a 2.3L diesel engine supercharged with a Compres CX 112 - 10 Pressure Wave Supercharger. A detailed description of the test vehicle is contained in Appendix A. The vehicle was loaned to the EPA by Brown Boveri Corporation (BBC), manufacturer of the Compres unit, for emissions and particulate testing.

Although, in general, supercharging is not a new technique for improving performance, the Compres CX 112 - 10 uses the concept of pressure waves to accomplish this goal. The energy of the highly pressurized exhaust gases is used to compress intake air by creating a series of controlled pressure waves in a rotating cell or tube. Fresh air is inducted into the cell and then sealed. The cell is then opened to an exhaust gas port which permits the higher pressure exhaust gas to expand into the cell, thereby compressing the fresh air. The cell is designed such that as it rotates a series of these pressure waves are created by opening and closing the cell to various size

[*Numbers in brackets designate references at end of report.]

chambers and subjecting the intake air to higher pressure gases. This action creates harmonic pressure waves within the cell and eventually a standing pressure wave results. The intake air and exhaust gases partially mix, producing an effective 10 - 15% EGR. The compressed intake air is then released into the cylinder intake port at a high pressure. As the cell continues to rotate, the exhaust gases are expelled, thus causing a low pressure in the cell. This low pressure creates a suction which is then used to draw in fresh air as the cell continues to rotate. The fresh air thus tends to cool the rotating cell and completely expel residual exhaust gases. A cutaway drawing of the Comprex unit is shown in figure 1. A more detailed description of the unit's operation can be obtained by referring to [2] of this report. Additional description of the process and test results for other vehicles are contained in [5] thru [10].



A = Gas casing D = Air casing
B = Rotor E = Exhaust pipe
C = Drive belt

Figure 1 Comprex Schematic

The exhaust gases of the engine flow through the gas casing (A) to the rotor (B) of the Comprex, transferring, by means of pressure-waves, energy to the air in the cells of the rotor and leaving the machine in the direction (E) towards the exhaust pipe. Fresh air drawn in at the air casing (D), compressed by the rotation of the rotor in the pressure-wave cycle, reaches the engine through the charge air pipe. For continuous control of the pressure-wave cycle the rotor is driven quite simply by a belt drive (C) which consumes about 1-2% of the engines output.

The sequence of pressure wave creation will only occur if the cell is rotated at the appropriate rpm. To control this process, the rotating cells are connected to the engine crankshaft via a V-belt at a fixed ratio. Since the belt drive is used only to rotate the cell, the drive consumes only a negligible amount of the engines power. This technique permits nearly instantaneous response of the supercharger, depending upon driving condition and demands.

The increase in power achieved with a Comprex is similar to that achieved with a conventional turbocharger.

Test Procedures

Using the EPA Light Duty Diesel Particulate Sampling System, exhaust emissions and fuel economy tests were conducted according to the Federal Test Procedure (FTP) [3] and the Highway Fuel Economy Test (HFET) procedure [4]. Four valid tests using each of these procedures were conducted to estimate the mean and standard deviation of the vehicle exhaust emission and fuel economy levels compared with the appropriate standards. Additionally, to assess the percentage of the total particulate emissions consisting of sulfate emissions, two tests using each of the driving cycles above and two tests using a cycle simulating a congested freeway (sulfate cycle) (Appendix B) were conducted.

Since the vehicle utilized for this assessment was equipped with a manual transmission, a shift schedule had to be selected. The manufacturer specified the standard shift schedule, with shifts at 15, 25 and 40 mph.

In the previous EPA assessment of the Comprex Unit, two areas of needed improvement were cited; inherent supercharger noise and transient smoke emission. On-the-road wide-open throttle and part-throttle accelerations were conducted to determine if improvements had been made in these areas since the previous testing of the Comprex system.

Test Results

Tables I and II reflect the vehicle exhaust emission and fuel economy results for the FTP and HFET, respectively. It should be noted in Table I that although the emission control system of the vehicle was not specifically calibrated to comply with U.S. emission requirements, the FTP results are well below the 1978 Federal Emission Standards. If the vehicle calibration could be refined slightly, the FTP emissions levels for the test vehicle would comply with the 1982 standards for both gaseous and particulate emissions.

Table III summarizes the results of sulfate measurements for each of the three driving cycles used.

When driven on-the-road, the vehicle exhibited good wide-open throttle acceleration and part-throttle response. The lag in acceleration usually associated with turbocharged engines was non-existent. Acceleration with the Comprex system was smooth and constant. The inherent high frequency whine of the Comprex system was muted by the new unit to a low, non-objectionable level. BBC claims this reduction in supercharger noise is a result of the new rotor design which incorporates noise reduction features. It should be noted that, supercharger whine was also minimal when the vehicle was tested (hood open) on the dynamometer. Pass-by sound tests were not conducted, however, therefore any noise control improvements could not be technically assessed.

Table I

Comprex Supercharged 2.3 Liter Opel Diesel
FTP Mass Emissions
(grams per mile)

<u>Test No.</u>	<u>HC(HFID)</u>	<u>CO</u>	<u>CO₂</u>	<u>NOx</u>	<u>F.E. (MPG)</u>	<u>Particulates</u>
80-0144	.46	1.71	329	.94	30.5	.289
80-0146	.43	1.73	339	1.01	29.7	.280
80-1388	- -*	1.60	336	.93	30.0	.269
80-1389	.45	1.55	332	.96	30.3	.282
Average	.45	1.65	334	.96	30.1	.280
1978 Emission Stds.	1.5	15.0	- -	2.0	- -	- -
1982 Emission Stds.	.41	3.4	- -	1.0	- -	.6

Table II

Comprex Supercharged 2.3 Liter Opel Diesel
HFET Mass Emissions
(grams per mile)

<u>Test No.</u>	<u>HC(HFID)</u>	<u>CO</u>	<u>CO₂</u>	<u>NOx</u>	<u>F.E. (MPG)</u>	<u>Particulates</u>
80-0145	.10	.59	238	.64	42.5	.127
80-0147	.12	.62	249	.69	40.7	.138
80-1392	- -*	.54	243	.66	41.7	.145
80-1392	.12	.56	247	.66	41.0	.139
Average	.11	.58	244	.66	41.5	.137

*No HFID Data due to instrument malfunction.

Table III

Comprex Supercharged 2.3 Liter Opel Diesel
Sulfate Particulate Emissions
(percent of total particulates)

Test No.	Test Type	% sulfate		
		Bag 1	Bag 2	Bag 3
80-1384	FTP	3.5%	3.5%	3.5%
80-1386	FTP	3.3%	5.2%	4.5%
80-1391	HFET	3.5%		
80-1393	HFET	7.0%		
80-1385	CF*	3.4%		
80-1385	CF*	2.5%		

*CF = Congested Freeway Driving Cycle.

Conclusions

- Except for HC, the vehicle met the 1982 Light Duty Diesel Emission Standards. Particulate Emissions were also significantly below the 1982 Standard of 0.6 gm/mi.
- Driveability of the vehicle was good. The Comprex concept of supercharging eliminates the low engine rpm acceleration lag associated with current turbo-charger designs.
- Although, pass-by sound testing was not conducted, the noise levels noted during both dynamometer and road testing were reduced to acceptable levels on the vehicle tested.
- The Durability of the Comprex unit was not assessed. It should be noted that there were no serious problems with the unit during this test program.

References

- [1] "Test results on a Mercedes-Benz 220D Diesel Sedan equipped with a Comprex Pressure Wave Supercharger"; report no. 76-2; Technology Assessment and Evaluation Branch, Emission Control Technology Division, Office of Mobile Source Air Pollution Control, EPA; August 1975
- [2] Peter K. Doerfler, BBC Brown, Boveri & Co, LTD.; "Comprex Supercharging of Vehicle Diesel Engines", SAE Paper no. 750335; February 24-28, 1975
- [3] "Particulate Regulation For Light Duty Diesel Vehicle"; Federal Register, Volume 44, No. 23; Thursday, February 1, 1979; pp. 6650-6671
- [4] Code of Federal Regulations; Title 40, Part 600, Subpart B, "Fuel Economy Regulations For 1978 and Later Model Year Automobiles - Test Procedures".
- [5] "Pressure Wave Supercharging"; Automotive Engineering, Vol. 85, Number 2, pp. 22-27
- [6] "Comprex May Benefit Small Automotive Diesels", Automotive Engineering, Vol. 88, Number 8, pp. 58-64.
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- [8] Tony A. Kollbrunner, BBC Brown, Boveri, & Co. Ltd.; "Comprex Supercharging for Passenger Car Engines", SAE Paper No. 800884; February 26 - March 2, 1980.
- [9] M. L. Monaghan, Richardo Consulting Engineers Ltd.; "Two Ways to Boost a Light Duty Diesel", DAE Paper No. 790038, February 26 - March 2, 1979
- [10] Nic. Ceoes, AG Brown Boveri & Cie.; "The Prinicipal of the Pressure-Wave Machine as used for charging Diesel Engines," Proceedings of the Eleventh International Symposium on Shock Tubes and Waves, July 11-15, 1977 pp. 36-55

Appendix A

TEST VEHICLE DESCRIPTION

Chassis model year/make - Comprex Supercharged 1978 Opel Rekord

Engine

type Diesel 4 cyl. inline
 bore x stroke. 92 x 85 mm/3.54 x 3.35 in.
 displacement 2.3 liters/140 CID
 compression ratio. 21.5: 1
 maximum power @ rpm. 83 BHP/62 kW @ 4100rpm
 fuel metering. Bosch/EPVE
 fuel requirement Diesel No. 2

Drive Train

transmission type 4 speed manual
 rear axle. 3.44: 1

Chassis

type 4 door sedan
 tire size. Continental 175SR14
 inertia weight 3000 lbs.
 passenger capacity 4

Supercharger

type Pressure wave
 model. CX 112-10
 manufacturer Brown Boveri Corp.
 length 328 mm (12.9 in)
 diameter 150 mm (5.9 in)
 weight 12 kg (26.5 lb.)

Appendix B
FTP, HFET and Congested Freeway Driving Cycle
Speed Versus Time Characteristics

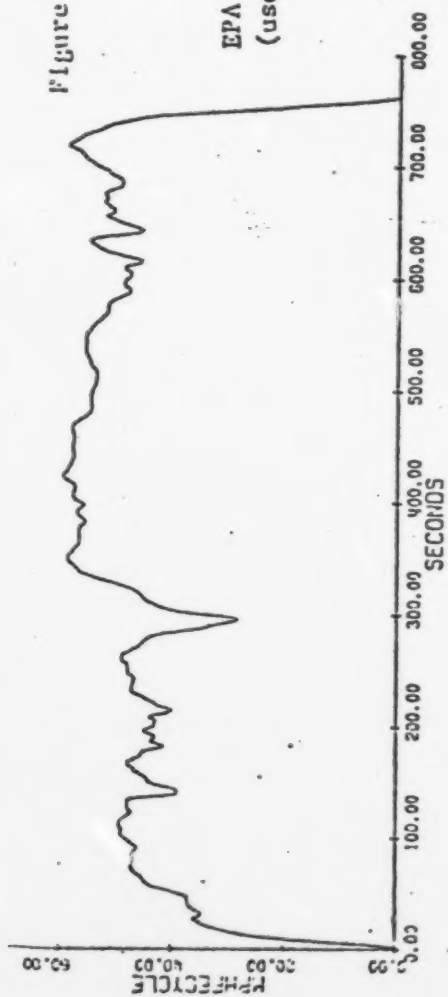
Driving Schedules

- 1) EPA Highway Cycle - Since the '75 FTP does not represent the type of driving done in non-urban areas, especially on highways, a driving cycle to assess highway fuel economy was developed by the EPA. The EPA Highway Cycle was constructed from actual speed-versus-time traces generated by an instrumented test car driven over a variety of non-urban roads, and preserves the non-steady-state characteristics of real-world driving. The average speed of the cycle is 48.2 mph and the cycle length is 10.2 miles, close to the average non-urban trip length.
- 2) LA-4 Urban Cycle - The LA-4 driving cycle is a simulation of on-road driving patterns for use on a chassis dynamometer. The cycle was developed from vehicle operational characteristics data collected on the streets and highways of the Los Angeles, California Metropolitan area. It is a non-repetitive driving cycle covering 7.5 miles in 1372 seconds, having an average speed of 19.7 mph and a maximum speed of 56.7 mph. A copy of the LA-4 driving cycle is provided as Figure 2.

The current Federal Test Procedure (FTP) utilizes the LA-4 with one modification. The first 505 seconds of the LA-4 driving cycle are repeated after a 10-minute engine "off" (soak) period. Therefore, the FTP driving cycle consists of 1877 seconds of vehicle operation with a total distance travelled of 11.1 miles.

- 3) Sulfate Cycle - The EPA Sulfate Cycle (Figure 2), known as the Congested Freeway Driving Schedule (CFDS), is a low speed cycle with an average speed of 35 mph. The cycle is 1398 seconds long and covers a distance of 13.6 miles. The CFDS represents the driving conditions of a high density expressway (i.e. low speed driving on a crowded freeway), and the sulfate emissions measured on this cycle are utilized by air quality planners to predict the effect of automotive sulfate emissions on air quality.

Figure 2: Official Federal Test Cycle



EPA Highway Cycle
(used in Highway Fuel Economy Test)



LA-4 Urban Cycle
(used in '75 Federal Test Procedure)

